

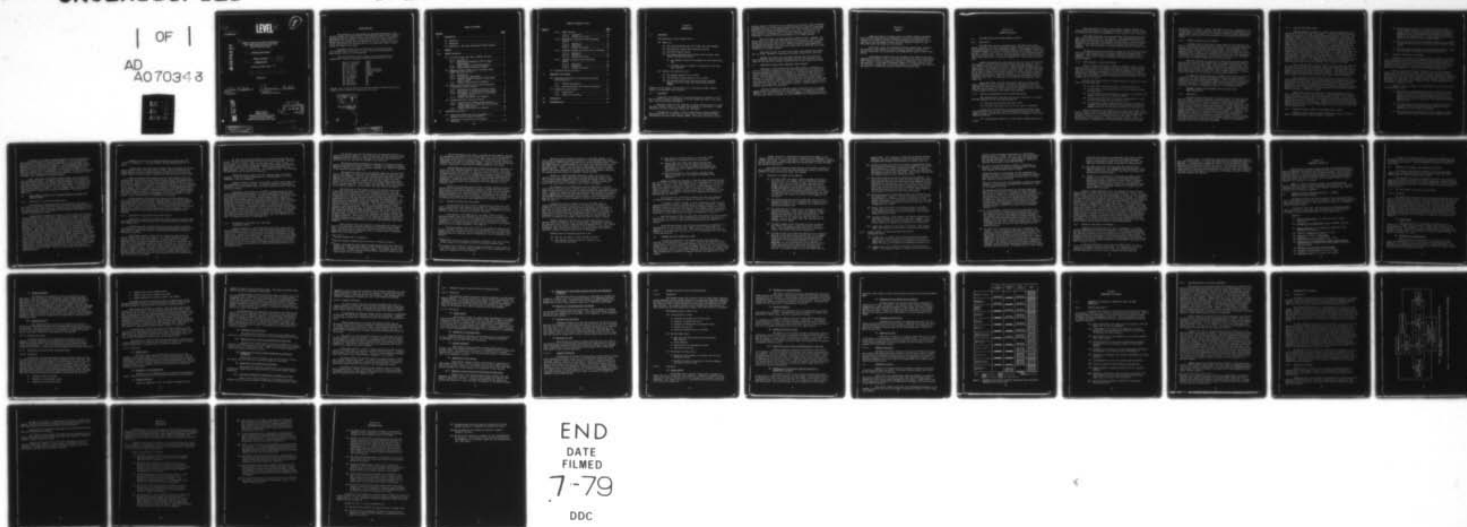
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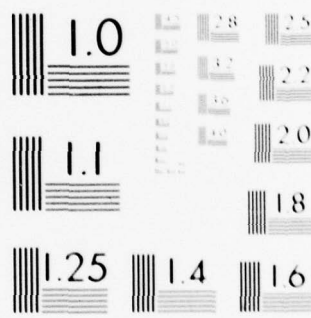
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SURVEY AND EVALUATION OF POTENTIAL
REAL-TIME INTERACTIVE FLIGHT TEST
FACILITIES FOR THE B-1, ✓

10 W. Deazley and W. Shed

Calspan Corporation ✓

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and many other at North American who provided detailed engineering data and insight into the flight test program and its needs.

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Section I
INTRODUCTION

1.1 OBJECTIVES

The objectives of this document are to:

(a) Report on:

- (1) The existing NR/LAD plans for flight test data handling
- (2) The McDonnell Douglas Real-Time Test Facility
- (3) The AFFTC Computer Center
- (4) The Grumman Real-Time Test Facility with the basic objectives of determining whether:
 - 1) the telemetry data will be adequate for real-time operation
 - 2) the AFFTC system is capable of supporting a real-time test operation

(b) Evaluate the practicality of:

- (1) The Grumman approach for B-1 tests
- (2) The McDonnell Douglas approach for B-1 tests
- (3) The proposed NR/LAD real-time system using equipment similar to the B-1 Flight Test Data Reduction System (FTDRS)

keeping in mind, always, the desirability of utilizing the AFFTC computer center to the greatest extent possible.

1.2 BACKGROUND

Originally, the objective of the initial portion of subtask 3.2.15-2 was to survey up-to-date information on the B-1 flight test plans, test equipment, and data handling requirements.

The basic reason for the trips was to assess the practicality of using the AFFTC computer facility to increase the efficiency of the Phase B-1 flight testing by the use of real-time flight test techniques.

The approach to subtask 3.2.15-2 as described in Calspan Management Memorandum M-014, was to evaluate the feasibility of near-real-time flight test methods using the AFFTC computer system. This was to be done by (1) gen-

erating conceptual designs for such a system for two specific types of display requirements and (2) using these conceptual designs as a basis for evaluating equipment requirements, programming costs, etc. This was then to be extended to as complete a system as considered to be practical. The output of the study would be a recommendation to the SPO of the practicality, cost, and advantages of pursuing the real-time approach to B-1 flight testing.

The trips were to be data gathering expeditions only. However, the entire subject of flight test plans for the B-1 was in such a state of change during this period that many of the original study objectives also changed. The growing awareness by the SPO, NR, AFFTC and others of the feasibility of incorporating a Grumman type flight test system into the AFFTC has had a major influence on the topics covered.

This report covers the first major step in the intended study which has, in itself, resulted in answering the original objectives of the study.

Because the results and conclusions derived from this study have been considerably different than originally expected, the discussion of the trips and the resultant findings are presented in as much detail as possible.

1.3 DEFINITION OF REAL-TIME INTERACTIVE FLIGHT TESTING

Real-time or real-time interactive flight testing (or displays) is the use of rapidly processed flight test data displayed in a form most effective for engineering evaluation or analysis at a rate permitting interaction between engineering personnel on the ground and the pilot in the test aircraft. The time delays involved in making the computations and absorbing the meaning of the displayed results of a particular test must be small enough to allow the engineer to communicate his satisfaction or concerns to the flight test controller and the pilot soon enough to permit re-testing, modifications, omission of the next step, or proceeding as planned. Typical delays of 1 or 2 minutes could probably be tolerated.

The key attributes of real-time flight testing are that it is interactive between the engineering and test personnel on the ground and the test pilots in the airplane, and that it provides answers to engineering questions not just data, where the answers are only available after considerable analysis.

Section II

SUMMARY

Trips were made by a Calspan team to the AFFTC, Douglas Long Beach, North American Rockwell/LAD and Grumman/Calverton during the period from 9 October to 26 October to obtain up-to-date information for evaluation of the practicality and advantages of using the AFFTC computer facility for near-real-time flight test monitoring and analysis.

This report covers the information obtained during trips, Calspan's observations of the systems and plans discussed, Calspan's evaluation of feasible approaches, and conclusions and recommendations based on these evaluations.

Considerable information has been obtained which indicates that major advantages are possible, with a real-time interactive data system, and that the AFFTC computer facility is physically capable of supporting a real-time flight test operation. The Grumman ATS approach appears to be most practical since the CDC 6400 at Grumman and the CDC 6500 computer at the AFFTC are very similar and adaption of existing ATS software should be relatively easy.

Section III

SURVEY DISCUSSION

3.1 AIR FORCE FLIGHT TEST CENTER (AFFTC) FACILITY

3.1.1 Description

The AFFTC data center is equipped with a CDC 6500 and has large amounts of modern up-to-date peripheral equipment which would be very useful for an engineering-level real-time-display system. This equipment seems to be scattered throughout a section of Building 3940 and would require a more orderly layout to permit easy access to various portions of the available systems. This is a critical point. The facility has expanded recently and the physical layout needs modification to group the equipment for a more close knit operation.

Present (and apparently firm) plans are for five (1 is in-house) CDC 241-1 graphics terminals plus numerous 211-100 remote CRT displays. These 211's perform the same function as ASR-33 remote teletype terminals but at a higher speed. The graphics terminals are ideally suited for engineering type real-time plots and interaction with an on-going flight. The 211 - 100 units can be used to display tabular results (which can be hard copied as needed). The 211-100 units have no "graphics" capability. All these units "talk" to Peripheral Processor Units (PPU) which act as interfaces between the Central Processing Units (CPU) (2 available in the 6500) and the displays, disks, tapes, etc.

The present AFFTC CDC 6500 has 10 PPU's feeding the CPU's which share a 98K 60 bit work core memory. The 6500 is only getting about 50% (maximum) CPU usage, partly because the total data handling has not needed more, and partly because it would be difficult to saturate the CPU's with the 10 CPU's presently available (for normal sized programs).

3.1.2 Additions Recommended by CDC for Real-Time Testing

CDC representatives indicated that the only additions to the AFFTC CDC 6500 required for real time testing might be:

- (1) The core size increased from 98K to 131K.
- (2) The PPU's increased from 10 to 20 (or less, if possible).

It was also indicated that the control programs developed by CDC and Grumman would need, at most, minor modifications for use on the AFFTC system. However, the EMR 6135 front end at AFFTC was designed to only handle tapes and therefore;

- (3) A preprocessor similar to the one used at Grumman would be required.

This preprocessor is made up from standard computer elements and would provide the conversions to engineering units, formation of data blocks for real-time processing, and preparation of data tapes and disk stored data.

With these additions, the real-time higher order analysis could be done on data chunks selected by the engineer. The computation programs and data would be entered into the high speed core storage of the CPU's by the main program and the CPU's would generate analysis results, and the necessary displays, to the peripheral unit (PPU) which operates the display for the engineer. Hard copy and storage of selected results would be available when required.

CDC implied that they would like to handle the real-time programming effort (at least integrating the systems and modifying the applications programs). They indicated that the Grumman preprocessor programs would be available in early 1973. (These according to CDC were developed jointly by CDC and Grumman.)

3.1.3 AFFTC Comments on Real-Time Testing

The B-1 Flight Test Director at AFFTC is strongly in favor of near real-time aids to speed up the decision process and permit flexible inflight test plan modifications. His contact with Grumman, Douglas, and NA/LAD has resulted in a thorough understanding of the real time potential of these three possible approaches to flight test, as far as they have been formulated to date. He is inclined to prefer the Grumman system for reasons to be discussed later in this report.

The B-1 Test Flight Director's primary reasons (in general) for wanting a real-time system are:

- (1) It will permit in-flight changes in test plan direction.
- (2) It will permit faster decisions for the next flight (GO-NO-GO and direction).
- (3) It will permit in-flight scrutiny of systems or situations which appear to be wrong or not working properly.
- (4) It will permit personnel (test pilots and engineers) to interact more effectively with the airborne crew.
- (5) It will permit longer flight durations because it permits adjustment of flight test objectives during flight with the subsequent assurance that the data collected is of good quality.

From the viewpoint of the personnel at the data center (Bldg. 3940) the B-1 is only one more additional AFFTC customer without any higher priority than many others, and it became apparent that any real time services must be made to "dovetail" with the other activities at the center. This point cannot be over-emphasized. Within these basic rules or restrictions, the data center is available to its fullest possible extent for real time

monitoring of B-1 flights. Clearly, the AFFTC is in favor of pursuing the use of real time if it can be shown that this will increase the likelihood of placing the Phase I (B-1) flight test at a level of completion where comprehensive engineering documentation will be available for an intelligent Production Decision.

3.1.4 Calspan's Observation and Comments

It appears that the FTC computer group depends on CDC personnel for most of their major system development. However, the FTC does have programmers working on many basic computational tasks as well as the development of an AFFTC package of programs under the acronym UFTAS. The development of this program package is expected to be completed before the B-1 flight tests start. Integration into a near-real-time system would require additional programming, but possibly not large amounts. The usability of UFTAS for real time operation is one of the basic determinations that must be made.

When CDC discussed the usefulness of CDC/Grumman developed programs, they failed to note that the Grumman executive program (operating system) is different from the CDC SCOPE, which is not tailored to real-time use. They also failed to note that the Grumman applications and analysis programs would still have to be obtained from Grumman. Many of these programs are Government property but efficient usage will require Grumman assistance in adapting them to the AFFTC and B-1 needs and in training AFFTC personnel.

To summarize, Calspan feels that the AFFTC facility has the potential to satisfy a B-1 real-time flight program with relatively small hardware changes and some major software improvements. A level of disarray and seeming inefficiency in the CDC 6500 usage at AFFTC seemed noticeable to Calspan as a cursory observation. Considerable AFFTC and CDC generated documentation describing the system was obtained to assist in a more detailed study.

3.2 MCDONNELL-DOUGLAS FLIGHT CONTROL AND DATA CENTER (FCDC) REAL-TIME FACILITY

3.2.1 Description

The basic Douglas FCDC system is flexible enough to accept data formats and channel capacities comparable to the planned B-1 data requirements. All data received on the TM link is converted to engineering units using linear (or nonlinear table lookup) calibration data of the transducers. Time history plots of selected channels are presented on the CRT display either in a roll-by mode or fixed for more careful scanning. Algebraic combinations of various parameters can also be displayed as time functions. Douglas can also provide cross plots, but no present programs or displays are available. No "higher order" analysis is available. The Douglas real time display is essentially a time history display system which is highly convenient to use. The Douglas FCDC also is very useful in preflight checking and in maintaining up to date calibration records for each flight. However no comprehensive preflight checks are automatically performed.

3.2.2 Previous FCDC Applications

McDonnell Douglas indicated that their system was highly effective and useful in the DC-10 flight test program. In this case the goals were aircraft certification by the FAA (with some engineering fixes on the fly), and customer acceptance as an economically effective transport. This fixed set of outputs was provided in 10-1/2 months of an originally predicted 13 month test program. It was originally estimated that the DC-10 flight test program would be 2000 flight hours and 15 months duration, with an additional 100 people required for data analysis and reduction. When Douglas proposed the use of a FCDC real-time flight test system they estimated a 1500 flight hour, 13 month duration program (with 100 less data reduction people required). They actually completed their FAA certification in 2-1/2 months less than their predicted (real-time) duration. They saved about 4-1/2 months, 500 flight hours and about 125 man-years of labor with respect to their original non-real time estimates. McDonnell Douglas considers the FCDC to be instrumental in accomplishing the task in this shortened time. Their data acquisition requirement was of the order of 4 to 5 times more complex than similar systems 10 years previous which at that time required 12 to 14 months to finish.

Post flight analysis was still a major factor in flight test analysis. The FCDC also functioned as an effective "quick look" system for selecting sections of the data for this higher order analysis. Decisions about the next flight (revisions in test plans, envelope expansion, etc.) were made on the basis of data obtained during the real-time testing. These decisions usually did not depend on higher order analysis, quick look, or batch processing.

Also, during a DC-10 test flights, monitoring of the test and the data obtained afforded good control of data quality and assurance that the particular test was done right. Alteration of an on-going flight test direction was possible if either an envelope limit was reached or if instrumentation failures or other situations developed which would normally have been cause for ending the tests. In this way long flight durations were maintained and good data for the entire flight was obtained.

Douglas feels that when exploring the various boundaries (flutter, Mach, stall, etc.) the pilot does not like to expose himself and the airplane to these boundaries any more often than absolutely necessary. The real-time system, with its data monitoring and corrections to obtain the proper standard conditions such as true airspeed, etc., insured that the pilot had reached the desired test condition. He, therefore, would not find out later that he missed the test point and again have to expose himself and the aircraft to these relatively hazardous tests.

3.2.3 McDonnell Douglas Comments on FCDC Adaptation to AFFTC

McDonnell Douglas has investigated three basic options to using the FCDC in connection with the AFFTC facility. These are:

- (1) The most direct solution is to relay the aircraft TM data to the Douglas/Long Beach Test Center via the Frost Peak relay station and do all data processing and display at Long Beach. Displays and data presentations would be monitored by NR personnel at the Douglas facility. Actual flight testing control would also be required at the Long Beach Center.
- (2) The next approach would be to relay the displays back to AFFTC for active interaction with the flight test at the AFFTC control center.
- (3) The most expensive approach, but the most responsive one, would be to duplicate the McDonnell Douglas system at AFFTC.

3.2.4 Calspan's Observations and Comments

The general conclusion that Calspan obtained at Douglas, relative to the DC-10 program, was that they saved calendar time, number of flights, and total flight hours from the amounts which were originally predicted to be necessary for FAA certification. The savings was on the order of 25% to 50% of their original estimates. These numbers are always subject to question since only one approach was used and no A-B comparison was possible.

When we compared the McDonnell Douglas system with the equipment available at the AFFTC computer center, the functional capabilities of the AFFTC hardware would easily match the McDonnell Douglas equipment; however, it seems unlikely that the hardware available at AFFTC and the software developed at Douglas are compatible. The McDonnell Douglas equipment consists of one XDS Sigma 7 and three XDS Sigma 2 computers. None of their options use any of the AFFTC computing facility.

Calspan's specific comments on the FCDC/AFFTC options, listed above, correspondingly include:

- (1) Even though the engineering needs might be satisfied by this approach, the operational needs would be unrealistic because of the remoteness of the McDonnell Douglas test center. In addition, the interactive features would be lost if the displays were used only for monitoring. The real-time advantages would be lost.
- (2) This approach is a more operationally acceptable method but the data transmission problems are quite difficult (from a bandwidth and from a security standpoint).
- (3) This approach is most responsive to the B-1 needs but wastes or does not make prudent use of the AFFTC computer facility.

In summary, the McDonnell Douglas approach to real-time flight test data displays is limited to time history displays. It can be argued that good strip chart records will serve the same need (if the preflight, book-keeping, and recall functions are omitted). If the McDonnell Douglas system were presently in existence at the AFFTC, it would be reasonable to use it. However, it is felt that the advantages of such a system at AFFTC do not match the probable cost of obtaining one. In addition, it would be prohibitive to develop new software to use the CDC 6500 at AFFTC as a substitute for the XDS Sigma 7 and 2 equipment at McDonnell Douglas.

After considering the McDonnell Douglas system, one conclusion became increasingly obvious. Assuming a real-time system will be operated at the AFFTC, then because of the similar computer equipment, the Grumman real-time system design (applied to the AFFTC computer center) is potentially the most fruitful approach, providing it is not unduly costly. It therefore became essential during our study to visit the Grumman flight test center as soon as possible to obtain more accurate information of its potential for AFFTC use.

3.3 NORTH AMERICAN ROCKWELL (NR) ON-BOARD RECORDING AND GROUND DATA STATION SYSTEMS

3.3.1 Description of On-Board Recording System

The on-board recording system has been documented in NR reports NA 70-550-4, TFD 70-1021, and TFD 70-1020, but some of the details were either not covered or were somewhat sketchy, resulting in an unclear definition of the instrumentation plan. Accordingly, the following is a description of the on-board instrumentation system.

Analog signals obtained from sensors or other sources are basically either high level or low level types. High level A.C. signals are converted to filtered high level D.C. and all signals are filtered prior to sampling. Low level signals (+ .040 volt) are pre-amplified to ± 5 volt levels using differential input instrumentation amplifiers having 100 dB common mode rejection (10^{-5} volt/volt). These ± 5 volt signals are then filtered prior to sampling. The pre-sampling filter characteristics are selectable by plug-in RC networks. Each group of sixteen data channels is multiplexed and digitized into 12 bit binary words representing the voltages out of the filters. Four of these multiplexing units are combined into a single multiplexing box having a 64 channel capacity. Provisions for 32 multiplexers are being made. Therefore the maximum total capacity is 2048 digital data channels. A central controller and data formatter are used to collect the data from the 32 multiplexers into a central storage register. This storage register is then scanned in the proper serial sequence to provide two types of outputs, (1) the telemetry data stream and (2) the four track interleaved serial data recorded on the on-board tape recorder. This reformatting operation has a total word capacity of 32,768 16 bit words per second. The 16 bit word contains 12 data bits and 4 bookkeeping bits.

Sampling rates out of the central controller can range from $4^{s/s}$ to $256^{s/s}$ in powers of 2. The most probable maximum sampling rate will be $128^{s/s}$.

A small number of digital word locations will be reserved for discrete data or sensor outputs which are digital in form. These data words can be strung together to obtain numerical accuracy exceeding one 12 bit data word. Single discrete events can also be combined into any one or more 12 bit words.

When the sampling rates available are not fast enough for the type of analog data which must be measured and recorded, analog FM recording methods will be used. FM-FM telemetry will also be used for ground monitoring of up to 21 FM data channels. The on-board FM recording capacity is 210 data channels split into 10 groups of 21 channels. Any one of the 10 groups can be transmitted to the ground. These 21 channels will be primarily flutter measurements and will be subjected to a real time spectrum analysis for on-line flutter analysis and flight envelope expansion. A third set of data under the general heading of acoustic noise and vibration measurements will also be recorded. At the moment, none of this data will be telemetered to the ground.

Of the possible 2048 digital data channels, NR/LAD estimates that about 1500 channels will be used for any single flight. All of this data can be telemetered to the ground station. Sensitive data will either be omitted from the TM data stream or mixed up in some special way which will make it highly unlikely that it can be decoded. It is believed that any such sensitive data which is needed for real-time applications will be available. The remaining discussion will not concern itself with security aspects of data handling.

3.3.2 Description of the Ground Data Station System

NR's plans to handle the in-flight data tapes after the aircraft lands were described in NA-72-907 NR report and in an oral presentation given by NR on 25 October 1972.

Calspan was given a detailed description of the computer system NR is developing for reducing the flight tapes to engineering unit tapes and into data tapes for higher order analysis of selected time intervals by specific engineering specialty.

This computer system, called the "B-1 Flight Test Data Reduction System" (FTDRS), also called the DICSY IV, is a fourth version of a method used on previous NR flight test programs. It uses twenty small "digital computers" which are called Interface Control Units (ICU's). These mini computers each have programmable read-only memories (PROM's) of 256 16-bit size words. These programs are loaded from a core or disk storage during the start up of the computer system. Each mini computer services one peripheral unit such as a graphics terminal, teletype, core memory, flight tape input, etc. Because of space limitations each ICU has only 5 internal working registers. Any computations requiring more short term storage will have to transmit data back to core until it is needed.

All ICU's are connected together on a dual high frequency data bus system. The total physical length of this bus is less than 2 feet. Each ICU is constructed on a single 4 layer circuit board about 1 foot² in area. It also contains the necessary voltage and impedance level drivers and receivers specifically needed for each peripheral. The 16 bit word available from memory provides 4 types of instructions: (1) Arithmetic/logic, (2) Branching, (3) Fetch/Store, and (4) Read or Set Counters.

Programming must be done on the most primitive level of machine language. It is most readily understood by a "non-programmer" as a "take-do-and-put" level of programming.

Calspan received a briefing, at the AFFTC, by NR on their flight test data acquisition and analysis plans. The briefing revealed an NR-proposed alternative use of their FTDRS computer system to operate a limited real-time-interactive system.

The hardware and software of the FTDRS is being tailored for quick look and engineering tape generation for post flight higher order analysis at the NR/LAD main computer center. The use of an FTDRS as a real-time system would require entirely new software, stored program options, methods for selecting these programs without disturbing the data flow or operations at other CRT locations and many other operating system details. Also, the FTDRS development is to have milestone checks which will exercise parts of the system and its software. The primary milestone is based on the commitment of the FTDRS to have it operationally capable of data reduction of the engine tests at Santa Susanna next spring. Prior to these tests, old B-70 data tapes will be used to exercise portions of the hardware and software. The engine test data reduction requirements will not require the full FTDRS system but the essential software and significant amounts of the total hardware will be used. No numbers are known on percentages, etc.

3.3.3 NR Comments on Data Needs For a Real-Time Interactive System

Calspan explained to each NR Engineering-Discipline group that we were attempting to define the outputs that each engineering group would want to have if they were able to have real-time-interactive capabilities during flight tests. Calspan specifically asked: Providing NR was able to get any type of data analysis and presentation of test results in real-time (or nearly real-time) during an actual test flight (1) what would they want displayed? (2) what analyses would they like to have? and (3) what types of information would they be able to use to permit NR to make engineering decisions about the quality of the data and whether the flight testing should proceed to the next planned point?

For the most part, the NR reaction (on the engineering level) to a real-time system was negative. They feel that they can fill their data needs through post-flight analysis and they question the cost effectiveness and improved utility of real-time as compared to non-real-time.

NR provided limited information in response to the above questions; however, their general response reflected a low level of planning or thinking about data outputs, form, types of answers, programs, etc. needed for analysis of data obtained during flight test.

The Engine-Test Group was in the planning stages for running tunnel tests of the engines and inlets at Lewis Research Center and later full scale tests at Santa Susanna. They have built instrumentation and special purpose computers to permit evaluation in real time (as well as record the basic data for post test analysis). Because they have been thinking along these lines, they did have ideas about what would be desirable real-time displays and the required analysis. Their primary real-time data output was a measure of the pressure profile of the air flow at the front face of the engine.

The distortion of this pressure pattern was defined by the ratio of the peak of the distorted pattern to the average pressure. This IDC (inlet distortion coefficient) plus other similar types of data provided a good measure of the engine stall onset or the margin before stall would occur. It also turned out that the data requirements for real-time distortion information are not included as part of the present NR telemetry plans. The engine pressure measurements require wide bandwidth data transmission of at least 80 channels (250-500 Hz bandwidth). This can only be transmitted via the FM/FM telemetry link which presently is only transmitting 21 flutter channels to the ground station. The constant bandwidth IRIG Type A FM data requires 180K Hz modulation range to permit 21 channels of data transmission. Four additional 180K Hz intervals hetrodyned up to: 200 to 380, 400 to 580, 600 to 780, 800 to 980K Hz would also be required to be able to transmit the necessary data to the ground. This total bandwidth requirement occupies 1MHz of overall bandwidth. This falls within the wide band telemetry allocations of 10MHz maximum occupied bandwidth.* This additional telemetry provision is definitely feasible if incorporated into the B-1 instrumentation plans early enough.**

Other problems which need attention to permit real-time analysis are based on the calibration procedures needed with the KULITE pressure gauges used. The KULITE sensors exhibit zero shift and sensitivity changes with temperature which require considerable effort to correct prior to computing engine inlet distortion data.***

* See IRIG Standard 106-71, Appendix A.

** Multiple Telemetry Transmitters would also be a feasible solution.

*** During a later meeting with Grumman, Calspan mentioned the inlet distortion problem and Grumman described how they solved these problems for real-time applications. Grumman also used KULITE gauges. They showed Calspan actual contour plots of inlet pressures showing percent distortion levels over the entire front face of the engine.

The NR Performance Group seems to consider the data analysis required for performance measurements to be so complicated that it must be performed by post flight analysis to be of any value.* Upon requesting an outline or a description of the computer programs planned for use in this area, Calspan was informed that NR plans on using UFTAS programs. However, they did not know the status of completion or which specific UFTAS programs are to be used.

The NR Stability and Control and Flying Qualities Group considers the use of real-time displayed analysis results to be (1) unneeded, (2) no more useful than strip chart outputs, (3) not cost effective, (4) not really used at Grumman (based on a NR visit to Grumman about one year previous to Calspan's visits). This is an area in which Calspan has considerable knowledge and we envisioned many possible data displays which would provide useful real-time information. Calspan was quite surprised to find that the use of real-time displayed analysis results was considered by NR to be unneeded, not cost effective, etc.

However, this NR group does feel that a tabular listing of stability derivatives or aerodynamic coefficients would be a useful real time output. When quizzed on what computer analysis programs they plan on using to extract these coefficients, etc., Calspan learned that they plan to use a Calspan program developed by W.H. Shed for analysis. Shed suggested that Calspan now has much better methods and that the program NR plans to use is only used as a starting routine for the more exact algorithms now utilized at Calspan.

3.3.4 Calspan's Observations and Comments

At the time of the first visit by Calspan NR had no plans for real-time or near-real-time data analysis for purposes of interacting with the in-progress flight test. Only 32 data channels were to be displayed in a ground station on strip chart recorders (Brush Mark 200 types).

With respect to the FTDRS method, the rather limited number of available program steps (240 adjustable and 16 protected) in the PROM's and the need for 20 of these ICU's to intercommunicate on the dual bus line at 5 megahertz bit rates results in a situation which from our rather limited experience in mini computer design is quite open for problems in both hardware functions and in software availability and capacity.

NR feels confident that this system will be working on time and will be able to handle the data word rates up to the maximum out of the data tapes. Calspan views this confidence with some reservations but feels that NR's prior experience must be a positive factor in reducing the risk of developing a new system.**

* Grumman described their dynamic performance techniques, which they consider to be as valid a test technique as any of the various classical ones.

** In a second visit to NR/LAD, Calspan pursued this subject in more detail but still has not been convinced that the FTDRS will be fully operational by the time it is needed for B-1 data handling.

There are certain attractive concepts in the FTDRS computer, e.g., the 20 small independent computers operating in a multiprocessor mode reduces the bottleneck problem usually associated with central processing units. Because the FTDRS system is a multiprocessor it can handle very high data rates but it has strong limits on what it can do with the data because of its very small program capacity. There is also the problem, mentioned previously, of being able to have twenty computers on the same dual bus at data rates of 5MHz without encountering data timing and impedance loading problems.

Relative to FTDRS development milestone checks, and since it is critical to the post flight data analysis planned by NR/LAD, Calspan feels that a careful progress-milestone plan should be defined and used as a gauge of the progress of the FTDRS during its development. Delays in making the system work could result in extremely costly flight test delays.

The proposed use of a FTDRS type system for providing a real-time data display system was viewed by Calspan as quite marginal in its ability to be ready in time and also in its ability to really satisfy the real-time-interactive needs. Calspan was originally uneasy and uncertain that the FTDRS would satisfy the NR original quick-look and data handling needs. The additional software (and probably hardware) development burden imposed on such a specialized system does not seem to be a realistic approach, to having a real-time capability at AFFTC for the B-1.

Calspan feels that any attempt to extend the FTDRS range of capabilities must follow hard evidence of its being able to perform its primary role of quick-look, engineering units conversion, and generation of data tapes for batch processing. There are enough unknowns in its being able to do the primary task on time that it is really futile to consider any other uses or dilute the primary design effort until it is successful in performing its initial role. This therefore means that the real-time use would not be available soon enough to have any effect on Phase I testing.

Calspan indicated to NR that the on-board system seemed to be an approach which is reasonable with no obvious risks. Calspan also indicated its uneasiness about the post flight ground data handling plans. Also, Calspan pointed out that there seems to be quite a lot of activity in the hardware development (both airborne and ground) but a logical flow of basic data requirements leading to hardware realization is not apparent.

Calspan posed the following questions to NR:

- (1) What are the goals of flight testing in detail?
- (2) What specific flight test points, maneuvers, etc., will satisfy each goal?

- (3) What specific predicted results, to the best of NR's knowledge will be obtained for each test point?
- (4) How do these test points and expected results get transferred into a series of flight test plans (for each flight) so that the test points are obtained, and the predictions can be compared with the actual vehicle characteristics?
- (5) What instrumentation, data channels, sampling rates, analysis programs, etc. are required to support these objectives?

Calspan indicated that question (1) has been partly answered in document NA-72-554, "B-1 Flight Test Program," but the information is superficial and needs "filling in" with considerable detail. Questions (2), (3), and (4) seem to be completely unanswered. Question (5) has been answered but in an "open loop" fashion which does not refer to the needs and reasons in the previous questions. It appears that the logical flow of requirements to test plans to required measurements to analysis and comparison with engineering estimates has not occurred.

NR recognized this concern and indicated that they are attempting to develop the logical sequence of answers to questions (1) through (5).

In summary, Calspan's attempt to obtain engineering inputs from the engineering side of the NR B-1 program was not entirely successful. Grumman, Calverton had similar difficulties with Grumman, Bethpage during their initial attempts at defining real-time requirements. The problems Calspan encountered are typical and add emphasis to the need for strong high-level B-1 management direction if a real-time-interactive flight test approach is selected.

Any half-hearted attempt at using real-time analysis will most probably be worthless. It requires a full commitment of resources and personnel at an early enough time to do the planning and engineering analysis required for success.

North American Rockwell has the prime engineering responsibility for developing the B-1 and therefore must commit itself to using a real-time approach if it is to be a useful one. Token acceptance of the kind which is implied in a statement like "we will use it if it is available" will not result in its effective use.

3.4 GRUMMAN REAL-TIME INTERACTIVE SYSTEM

A detailed description of the Grumman System, which includes a CDC 6400, is not presented here. The point is that the CDC 6400, CRT scopes, preprocessors, and various peripheral equipment also exist at AFFTC (and to a greater extent). The description of the Grumman System, which is the combination of this physical facility, the Grumman Real-Time Software, and the Grumman Flight Test Philosophy (which includes proper management and operational structure) is best accomplished by describing the general features and capabilities of the system.

Calspan was given a comprehensive description and summary of the complete system, the way it is used, how it operates and the advantages of such a flight test system. Calspan was exposed to the real-time-interactive capability and the operational planning (organizing and systematizing) of tests necessary for efficient utilization.

The disciplined approach toward testing, which Grumman considers to be a necessary part of a truly real-time-interactive system, is never fully realized in a more conventional flight test program.

3.4.1 Description of Grumman System Features

- (1) In actual flight test usage, complex programs for analysis are practical - for example: The F-14 SAS ON-OFF behavior. First, a test run at a specific flight condition, SAS ON - control input results in (1) automatic identification of primary coefficients in equations of motion, (2) prediction of SAS OFF behavior based on SAS ON measurements, (3) presentation of SAS OFF engineering predictions (prior to flight) for comparison and (4) if both SAS OFF predictions are close to each other and indicate no unsafe situation omit SAS OFF test point.
- (2) The Grumman Operating System TeleSCOPE (R) differs from the standard CDC SCOPE system in important ways (default options, priority assignments, etc.) considered to be essential for real-time-interactive use.
- (3) The organizational structure of the user must be fitted to real-time operation. Close contact is essential between engineering disciplines and flight test personnel. Engineering representatives for each discipline must be incorporated into the flight test team very early in the program. Much of the total flight test planning must be provided by these people.
- (4) Standard programs usually developed for batch processing are replete with options, nested subroutines and other "fat". These programming methods must not be permitted, because they produce inefficient computations.
- (5) Preflight checks by the real-time computer can be automatic, and only out-of-specification channels need to be flagged. Flights are only given a go-ahead when all channels are functioning properly (maintaining good hardware becomes essential). It is much more difficult to explain to Management why an instrumentation failure cancelled out a flight than answering the traditional question of why a test flight was useless because of an instrumentation failure. The delayed flight is much less costly than the

wasted flight. This reversal in flight test priorities required some major changes in management priorities because of the fly-no-matter-what syndrome often fostered by incentive fees, etc.

- (6) Preflight meetings with the pilot provide a comprehensive review of the expected engineering results and a discussion of alternate tests which might be required during the flight. In this way the pilot has a much better understanding of his test objectives and possible alternate test directions. This reduces substantially the communications necessary during the flight.
- (7) Post flight meetings are used to review the test results. The pilot is presented with hard copies of actual flight test results for comparison with the predicted ones and for immediate correlation with his observations of the test. This cycle of predicted results in the preflight meeting and actual test results in the post flight meeting generates pilot confidence and acceptance of the real time approach and results in a close, honest relationship between the engineering and flight test groups.
- (8) Real-Time-Interactive engineering analysis and optimization can be accomplished. Example: In-flight adjustment of each element of the engine inlet geometry was made to optimize the inlet geometry scheduling as a function of flight condition. The same process using more conventional methods would have used an order of magnitude more flights.
- (9) Flight safety monitoring at any definable level is possible. No real attention needs to be directed towards flight safety until flagged items appear on the CRT displays. More detailed analysis can then be made.
- (10) Envelope expansion, flutter sweeps, and exploring boundaries of the flight envelope can be done in real time. Example: A complete flutter survey was made by Grumman in 16 flights instead of the predicted 82 flights (using standard test procedures).
- (11) Longer more productive flight tests can be made. This permits fewer total flights or more data for a given duration program.

3.4.2 Grumman Comments on AFFTC Real-Time Testing Using the Grumman Method

- (1) Grumman does not believe that a real-time-interactive system would require much more than 10% of the AFFTC CDC 6500 CPU usage while it is in operation. This means that the remaining 90% of CPU time can be doing batch processing, payrolls, etc.
- (2) Grumman feels that no additional hardware would be needed at AFFTC. This statement cannot, of course, be made with absolute

certainty without detailed investigation of the EMR 6135 system capability at AFFTC. But it is felt, from discussions with EMR, and knowledge of the Grumman CDC 1700 "front ends" that the EMR 6135 units can be re-programmed to function as real-time "front-ends" to the AFFTC CDC 6500.

- (3) The use of the CDC 6500 system at AFFTC is inefficient as presently configured (Calspan received minor hints of this when visiting the computer center at AFFTC).

Grumman discussed, in some detail, how the Peripheral Processing Units (PPU's) at the AFFTC are not being used properly. They also pointed out that the CPU is being used to do tasks which should be done by the PPU's.

They also pointed out that the environment in which the computer operates is insufficiently controlled and contributes to much of the computer down time.

The Grumman CDC 6400 installation has the best reliability history of any CDC system. The AFFTC has nearly the worst. Part of this is based on not attending to "minor" details; e.g., not waxing the floors, not forcing failures of weak points during off hours so they can be repaired before the computer is needed for flight tests, not controlling the main supply voltage levels constant enough during critical use times, not controlling the temperature in the rooms more precisely (better than spec allowances) and others such as equipment placement, etc.

- (4) It is also Grumman's observation that the total usage cost of a real-time system, versus batch processing only, is less. This happens because the programming discipline developed for real-time operation when applied to batch processing increased the batch processing program efficiency, and less total computer time (real time + batch) was needed than if batch processing only were used. These observations were a surprise to Grumman but they are based on their experience with the present operation.
- (5) The flight test controller was more often an engineer than a pilot. In fact the piloting experience of the flight test controller was not considered to be any significant aid. This was contrary to the McDonnell Douglas operation, where the flight test controller was always a DC-10 test pilot. Calspan questioned a F-14 test pilot in an oblique way to see if he might really feel better if the controller were an experienced test pilot. His response was that he definitely preferred an engineer, because he wanted engineering answers and evaluations, not pilot type evaluations. He remarked that his chase pilots

serve that other need and an experienced test pilot is always on call if the situation requires ground based assistance. From our observations, flight test controllers are "born, not made" and a selection process is required to find good ones.

- (6) The AFFTC facility has more equipment and computing power than the Grumman ATS. The Grumman CDC 6400 can process 3 simultaneous flights with about 50% CPU load while also doing batch processing of previous flights.
- (7) Grumman is very interested in configuring the AFFTC computer facility to be able to operate as a real-time-interactive system and has spent considerable time and money in studying the problems associated with such a task. As a for profit corporation, Grumman probably expects to get additional stature in the industry by developing a system for the AFFTC, and to improve their own system.

Finally, Grumman emphasizes that it is essential to have the total planning done, in detail, when using a real-time-interactive system. The basic reason is that there is no time for debating what to do next, or what alternative tests or analyses should be made when the airplane is in the air. In addition, the real-time interactive capability permits monitoring combined test objectives and hence it reduces the number of flight data runs needed at any one flight condition (often to one combined test or test "block"). This combining of tests requires a complete plan for every flight prior to the actual initiation of the flight test program. These plans are not simply a listing of test altitudes, Mach numbers, etc. They must also include all the engineering objectives, required for real-time-interactive displays and the expected test alternatives which may result from the analysis of actual test results. This approach to flight testing is traumatic at the very least to personnel in the engineering groups because it requires considerably more homework before testing begins. But Grumman has discovered that once the initial shock dissipated, both the engineering and the flight test groups (traditionally separated) are now operating together, and much more efficiently and enthusiastically.

3.4.3 Calspan's Observations and Comments

Calspan was literally excited by the new potentials of the flight testing techniques which Grumman has initiated. The McDonnell Douglas system has some similar potential but their approach, as it is presently configured, only provides convenient time history plots and no higher order analysis. The McDonnell Douglas test philosophy is still centered on post flight analysis. Grumman has reversed the approach to using real-time-analysis for decisions and evaluation, with the post flight analysis as a comprehensive follow-up to the basic in-flight analysis.

A real-time-interactive system like the Grumman ATS is not just a collection of computer hardware and software. It is an entire concept and requires considerable restructuring of flight test organizations and a different approach to its use in order to realize its full potential.

A further point - the discipline generated in the engineering analysis and flight test planning, in itself, justifies promoting the real-time-interactive approach. It appeared that a significant amount of the clockworklike flight test operation at Grumman was simply the result of the excellent pre-planning (which was a necessity for real-time operations). The end result was therefore a more carefully thought-out and planned test program and a very rapid capability (through the real-time analysis and display) for in-flight decisions concerning test plan progress and direction.

Section IV

EVALUATION DISCUSSION

This discussion includes itemized benefits which should be derived from an interactive data processing system and what is required both in equipment and personnel to accomplish such a system in general. With this as a reference point the existing and proposed systems of North American Rockwell, Air Force Flight Test Center, McDonnell Douglas, and Grumman are evaluated. Also the contribution that the B-1 SPO will be required to make in order to implement such a system is discussed.

Again, in order to eliminate confusion the term "interactive" will be used here to describe data processing during flight test. This then describes the time period in which a test engineer can observe test data and interact with the flight in progress.

4.1 INTERACTIVE FLIGHT TEST DATA PROCESSING - A GENERAL OUTLINE OF EXPECTED BENEFITS

The general benefits that should be gained from Interactive Flight Test Data Processing are listed here to establish a basis for judging any particular system under discussion. This also provides a basis for a comparison between different systems.

It should be noted that, where practical, the following benefits should be the goals of any flight test data processing system regardless of whether it is an interactive system or a post flight system.

Benefits:

- (a) Improved flight safety from limit and rate of change monitoring.
- (b) Validation of instrumentation through preflight checking.
- (c) Answers displayed to the engineering disciplines while the test is in progress.
- (d) Immediate validation of success of a test.
- (e) Reduction of number of test points.
- (f) Modification of the test plan during a test.
- (g) Elimination of the requirement for post flight analysis that is needed to validate the current flight and to plan the next flight.
- (h) Reduction in post-flight data processing.
- (i) Increase in productivity of each test flight.
- (j) Reduction in cost of the flight test program.

In view of the expected benefits of Interactive Flight Test Data Processing, there are certain general requirements that must be addressed to realize these benefits. These requirements are listed in Section V of this report.

4.2 EVALUATION OF POTENTIAL DATA PROCESSING FACILITIES

The following discussion is addressed to the data processing facilities or systems associated with the Air Force Flight Test Center (AFFTC), NR/LAD, McDonnell Douglas, and Grumman.

The evaluation mode here is subjective in nature and includes both pertinent descriptive information and Calspan commentary. Underscored paragraph subject headings for each of the four organizations relate to the items found in the list of benefits for interactive Flight Test Data Processing in Subsection 4.1.

4.2.1 Air Force Flight Test Center Data Processing

4.2.1.1 Evaluation

The AFFTC Data Processing Center is extremely well equipped with hardware for processing flight test data. However, the application of this hardware to the task of processing flight test data is poor. Since the primary task of the data processing center is to support the flight test operation, the executive (operating system) program of the computer system should be designed to effectively handle flight test data. The data processing center has taken a Control Data Corporation executive program which was designed for general purpose scientific and business batch processing and is trying to implement flight test data processing under control of that system. This makes the system awkward to use and leads to inefficient use of the system resources.

(a) Flight Safety

This system has all of the hardware capability to do a thorough job of flight safety monitoring. However there has been no software developed to take advantage of the tremendous power of the system to perform this task. The system is capable of monitoring every variable (that pertains to flight safety) and "alarming" on limits and rates-of-change. It should be programmed to do this.

(b) Validation of Instrumentation

This system has the capability to very rapidly check the entire instrumentation system of the test aircraft during the preflight operation. In a matter of minutes the sensors, channel assignments, scale factors, and TM transmitters and receivers can be validated. Again, however, the software must be developed to do this.

(c) Answers Displayed

The answers to be displayed to the test engineers can take many forms: they can appear as time histories, engine pressure patterns, test aircraft response (compared to predicted response), extracted stability derivatives, etc. The engineers, from the various disciplines concerned, must define the answers that they want, in order to interact with the test, before the system can be programmed to produce the answers. The data processing center is relying heavily on the UFTAS system to supply them with the necessary computer programs for computing the answers required. At this time UFTAS is in the formative stage and it is not likely that it will produce applicable software in time to be ready for the B-1 flight test program. Analysis programs supplied by UFTAS will require modification to adapt them to the data source and display system.

(d-j) Remaining Points

The remaining points in the list of benefits that should be derived from Interactive Real Time Data Processing will produce the same sort of discussion. The major points are that the system has the hardware capability to do the job, the existing software is not adaptable to doing the job, and much of the software required is not prepared or even defined.

4.2.1.2 Calspan Conclusions

It will be impossible for the AFFTC Data Processing Center to be prepared to perform interactive data processing at the start of the B-1 flight test program unless they can acquire much of the necessary software from an outside source. In fact it is doubtful whether they will be able to perform effectively in post flight data processing without outside assistance.

4.2.2 NR-Proposed Interactive Data Processing System

4.2.2.1 Background

NR proposes to perform interactive data processing by applying both the AFFTC system and their own data reduction system at LAD to the task. They plan on doing this by adding equipment at the AFFTC data processing center to compress the TM data and then transmit this over telephone lines to LAD. At LAD the data will be processed by the same data reduction system that they use for post flight processing. At the same time they propose to use the AFFTC system to perform interactive data processing using whatever system they have. Then displays generated at LAD will be transmitted by telephone line to AFFTC. With this system they propose the following six displays at LAD and AFFTC:

- Parameter versus time plots
- Parameter versus parameter plots
- Computed data versus time plots

- Computed data versus parameter plots
- Computed data versus computed data plots
- Flight conditions in letters, symbols, and numbers

The FTDRS data reduction system at LAD is an integral part of the proposed interactive system. A limited description follows of that system, for which hardware is being procured and software is being developed.

This system was designed to accept as input the data tape recorded on board the test aircraft. The tape includes both PCM and FM data. This data is fed into the system in real time, and the system in turn converts the data to engineering units and displays selected time histories on CRT's. The interested engineer, by observing the CRT display, can then select specific time intervals for further analysis. When this editing process has been completed, the engineer's requests for time intervals of specified parameters are fed back into the system, the data tape is played back through the system, and these intervals are recorded on an IBM compatible tape. This tape is then taken to a large general purpose digital computer for analysis.

To perform this function the system has 20 mini computers (256 16 bit words and 5 registers each) tied together on a dual bus and also to peripherals such as tape readers, printers, core memory, disk memory, CRT's, and TTY. These mini computers (called ICU's) control the information flow to and from the peripherals and convert data to engineering units.

The interactive system at AFFTC has been described in Subsection 3.1; it was determined that it could not be functional in time for the B-1 program without outside help. NR cannot supply the required assistance.

4.2.2.2 Evaluation

(a) Flight Safety

NR has not given any indication that they plan to use the tremendous power of the digital computer to improve flight safety. They are planning to use FM/FM telemetering to a special ground based computer which will perform real-time spectrum analysis on flutter measurements. In addition to this there will be 10 cockpit displays which may be used to monitor cockpit selected flight safety variables, and 32 raw data channels on strip chart recorders on the ground.

(b) Validation of Instrumentation

NR plans to use a separate system for preflight instrumentation check. There are no plans to use the interactive system for this function.

(c) Answers Displayed

Listed in Subsection 4.2.2.1 six types of displays that NR

proposed to supply in an interactive system. The answers available would then be limited to appearing in these forms.

In discussions with NR data reduction system personnel, they could only demonstrate a capability of producing the first of these displays-- "parameter versus time." The other five displays are questionable because of the limited computational capability of the data reduction facility. It was also stated by these same NR personnel that they do not expect the various engineering disciplines to request anything more than the first display. If other displays are requested, it would not be before the beginning of the flight test program!

NR representatives for propulsion, performance, and stability and control have not yet determined the answers they would desire from either interactive or post-flight data analysis. The performance representative indicated reliance on UFTAS to supply the necessary software to meet his needs. The stability and control representative indicated a desire for answers in the form of extracted stability derivatives from flight test data. This analysis would use a technique developed by Calspan and prepared for NR's XB-70 flight test in 1966. Considerably better techniques are presently available.

(d) Validation of Test Success

The proposed NR interactive system would only validate test success to the extent that time histories of measured parameters would allow.

(e,f) Reduction of Test Points and Modification of Test Plan

Because of the limited digital computer facilities for the NR-proposed interactive system, it would not display trends, relate test responses to predictions, or reveal danger areas. These are the elements required to reduce test points and modify test plans.

(g) Eliminating Post Flight Analysis Required for Validation & Planning

This benefit would be limited, under the NR-proposed system to the extent that time histories of measured parameters would allow.

(h) Reduction in Post Flight Data Processing

The proposed NR interactive system shows little potential for reducing post flight data processing because of its limited digital computer capability.

(i,j) Increase in Flight Test Productivity and Reduction in Cost

There is very little potential for increasing productivity or reducing cost by using the proposed NR interactive system because the limited

capability of the system will not produce the necessary information to allow the test engineer to make the "press on" decision. Therefore, the test aircraft would have to land and wait for this decision. More flights would be required, consequently increasing the cost of the flight test program.

4.2.2.3 Calspan Conclusions

It can be readily seen from the above discussion that there is little potential in the NR system for meeting the desired goals of an Interactive Data Processing System. Therefore time and money spent on producing such a system would be a waste of engineering talent and Government funds.

In performing this subtask, Calspan found it necessary to investigate the NR plan for post-flight reduction of flight test data tapes. Comments on this plan, although not a prescribed part of the subtask, are appropriate here.

Cursory examination of this plan has generated doubt that the NR-proposed system has sufficient hardware to perform the prescribed tasks. It is also doubtful that, within the limits of the hardware, software can be developed to perform these tasks on time for the first flight test. A more detailed investigation is in order to ascertain whether this system can do the job.

The purpose of this interactive system is to permit data selection by test engineers. For effectiveness, the system should be able to display time histories of measured variables in engineering units, vary the period of time being displayed, and hold a period of time on the display for closer examination. This entails considerable logic and computation, which this system is not likely to be able to handle.

Since this system is a "one of a kind" design built by NR, no manufacturer's software will be available to generate the CRT display. Therefore, NR will have to develop this software. This is a large software development task complicated by the limited hardware capability of the system.

At present there is no absolute plan for a backup system to reduce the in-flight recorded data tapes. If further investigation indicates that this system is indeed marginal, consideration should be given to a backup system that would reduce the data tapes to an IBM compatible format.

The above discussion illustrates many doubtful aspects of the NR data reduction plans. Further investigation is likely to turn up problems in handling the FM data, developing an operating system, inputting the data tape, and generating the IBM compatible tape.

4.2.3 McDonnell Douglas Interactive Data Processing System

4.2.3.1 Background

The McDonnell Douglas interactive system is centered on an XDS Sigma 7 digital computer. TM data is received at a relay station, re-transmitted over a microwave link to the Flight Control Data Center at Long Beach. There it is received into the data processing system, decoded, converted to engineering units and displayed on CRT's and Strip Charts as functions of time. Hard copies of CRT displays can be made on request for the test engineers.

4.2.3.2 Evaluation

(a) Flight Safety

This system provides for flight safety improvements to the degree that presentation of flight safety variables (in the form of plots and tabular listing as a function of time) allows. The test engineer in this system is a test pilot, and he can observe the safety aspects in an environment where he is not subject to the disturbances of a flight test pilot. Presently, there is no limit or rate of change monitoring within the computer system. However, with the computing capability of the Sigma 7 this could readily be accomplished.

(b) Validation of Instrumentation

Although preflight validation of instrumentation is not performed by this system it could be handled readily with the computing capability of the Sigma 7 and its CRT's and hard copy system.

(c) Answers Displayed

Time history displays provide a limited answer capability; however, much more meaningful information can be obtained within the capabilities of this system. The system has the capacity to perform much more complex analysis and to display it within the interactive time limits. Software would have to be developed to do this.

(d) Validation of Test Success

Time history displays provide a good method for validation of test success in most cases. However, answers based on more complex analysis will yield a greater certainty in validation and provide for cases where time history displays have little bearing on the validation of test success.

(e,f) Reduction of Test Points and Modification of Test Plans

Answers from a more complex analysis than available from time-responses are usually required to allow the test engineer to eliminate test points or modify the test plan. Although this system has the capacity to provide these answers it is not presently incorporated in the system software.

(g) Elimination of Post-Flight Analysis Required for Validation & Planning

Time histories alone are usually not sufficient to validate the success of a specific test or to determine whether it is desirable and safe to move on to other tests. Therefore, this system has limited capability for eliminating the post-flight analysis required for validation and planning.

(h) Reduction in Post-Flight Data Processing

This system will reduce post-flight data processing by allowing for considerable editing during the flight. Data, which from on-line observation by the test engineer can be determined to be inadequate, can be eliminated from post-flight analysis.

(i) Increase in Productivity

A McDonnell Douglas pilot who participated in the DC-10 test program was very enthusiastic about the system because he felt that (1) it reduced the times that he had to expose himself to marginal situations, (2) it improved the chance that a test would be performed correctly the first time and (3) he is more willing to proceed with tests under marginal conditions when the test engineer (pilot in the ground station) assures him that it is safe. Thus more test points per flight and, in turn, increased productivity were realized.

(j) Reduction in Cost

Even through the McDonnell Douglas system has not come close to its potential as far as engineering interaction with flight tests, it has produced considerable savings in their DC-10 flight test program. They consider that the expenditure for the system has been worthwhile, even if they limit their gains to their present experience.

4.2.3.3 Calspan Conclusions

Implementing the McDonnell Douglas system at AFFTC does not appear to be a practical solution for the B-1 or the AFFTC Data Processing Center. Since the McDonnell Douglas system centers on a Sigma 7 digital computer and the AFFTC system is centered on a CDC 6500, it would be necessary to rewrite much of the software to use the AFFTC system. This would be costly and it is unlikely that it could be accomplished on time for B-1 use. Another approach could be to lease a system identical to the McDonnell Douglas system, and install it at AFFTC for the B-1 flight testing, but it would not take advantage of the excellent equipment already available at AFFTC - nor would it increase the capability of the AFFTC system.

4.2.4 Grumman Interactive Data Processing System

4.2.4.1 Background

The Grumman system (ATS) centers on the CDC 6400 digital computer. It was developed with the primary objective of supporting flight test operations. The executive program (operating system) for the system was designed by Grumman with this objective and has therefore made the on-line processing of test data very efficient. The computer system is also available for large amounts of data processing other than flight test support, even when tests are in progress.

The Grumman system is made up of:

(1) A pre-processor, which:

- acquires and decodes the TM data stream
- converts to engineering units
- displays time histories in engineering units
- records all the data
- edits and transmits data to the 6400

(2) The CDC 6400, which:

- does real time data reduction and interactive data analysis
- drives displays
- records data for intermaneuver recall
- does batch processing

(3) The display section, which:

- allows the test engineer to interact with the data processing system
- supplies information required for the test engineer to interact with the test.

4.2.4.2 Evaluation

(a) Flight Safety

The Grumman system monitors flight safety variables for limits and rate of change and calls attention to dangerous situations by generating data analysis programs which will indicate the existence of marginal conditions. One Grumman test pilot is convinced that the ATS actually saved an F-14 during a flight test.

(b) Validation of Instrumentation

This system completely validates instrumentation during pre-flight through the TM system. This provides a check for the entire data system from sensors in the aircraft to scale factors and channel assignment in the data processing system. If errors are encountered they are brought to the attention of the test engineer by flashing pointers on the CRT display. The entire validation can be accomplished in approximately 20 minutes.

(c) Answers Displayed

Samples of CRT displays from the Grumman system have shown such engineering data as: instrumentation data in tabular form, engine inlet pressures in contour plots, and stick force/g in X/Y plots.

It can be expected that not all the answers required for B-1 testing are available in existing software. Therefore, if the decision to go interactive in flight test data processing using this system is made, it will be necessary to define the answers required by the B-1 so that the software can be prepared and modified and in time for flight testing.

(d) Validation of Test Success

The ability of this system to produce engineering answers in interactive time will allow absolute immediate validation of test success in most instances and it will yield a high degree of certainty in all cases except when an unusual or unanticipated situation arises during a flight test. If this should happen it is likely that post-flight data analysis will be required to validate the test success.

(e,f) Reduction of Test Points and Modification of Test Plan

Because engineering answers are available in this system, it is possible for the test engineer to determine that certain test points are not required. This can be done by comparing test trends with predicted results and determining when the increment to the next point can be increased. When a system failure occurs which does not endanger flight safety, test plans can be modified and the flight can proceed. Typically, these failures would occur in instrumentation; the ability of the system to pinpoint instrumentation failures would allow the test engineer to modify the plan to tests that do not require the failed instrumentation.

(g) Elimination of Post-Flight Analysis Required for Validation & Planning

The ability of this system to produce engineering answers during flight in most cases eliminates the requirement for post-flight analysis to validate the current tests and plan the next flight. When unusual or unanticipated events occur during flight test it is likely that further analysis will be required. The data selecting and recall capability of this system

allows for rapid display of data and additional analysis in the batch processing mode.

(h) Reduction in Post-Flight Data Processing

In many instances the analysis performed in interactive time will be all that is required. The ability of the system to validate instrumentation, supply engineering answers during flight, and allow the test engineers to select hard copy of displays as they desire will yield analyzed data in report form. Where post-flight analysis is required, it will be enhanced by the editing, which can be performed by the test engineers during flight.

(i) Increase in Productivity

Eliminating test points and modifying test plans will increase the productivity for each test flight. Speeding up the test validation and the planning will make the test program move faster. The combination of these will increase the productivity of the flight program as a function of both time and money.

(j) Reduction in Cost

Cost will be reduced by increased productivity and a decrease in the amount of data analysis required for flight testing. In addition, the organization and planning required to implement this system will be of benefit to the entire program and in turn should reduce the cost of areas of the B-1 program other than flight testing.

4.2.4.3 Calspan Conclusions

The above discussion indicates that using the Grumman ATS system at the AFFTC Data Processing Center could be of great value to the B-1 program. This could be accomplished economically and in the time required because the hardware elements of the ATS and AFFTC systems are compatible, and most of the software developed for the ATS system will be applicable to the AFFTC system with minimum modification.

4.3 CONDENSED EVALUATION

Figure 1 is a summary matrix of Calspan's subjective evaluation of each facility/system in terms of the possible benefits gained from Interactive Flight Test Data Processing.

Since there is no standardized method established for measuring the relative quality of an interactive flight test data processing system, Calspan has used a rating system designed for this report. Calspan feels that this rating system realistically and graphically represents the relative merits of the systems evaluated.

This matrix summary illustrates the overwhelming advantages of the Grumman ATS system over the other systems in meeting the needs of the B-1 flight test program.

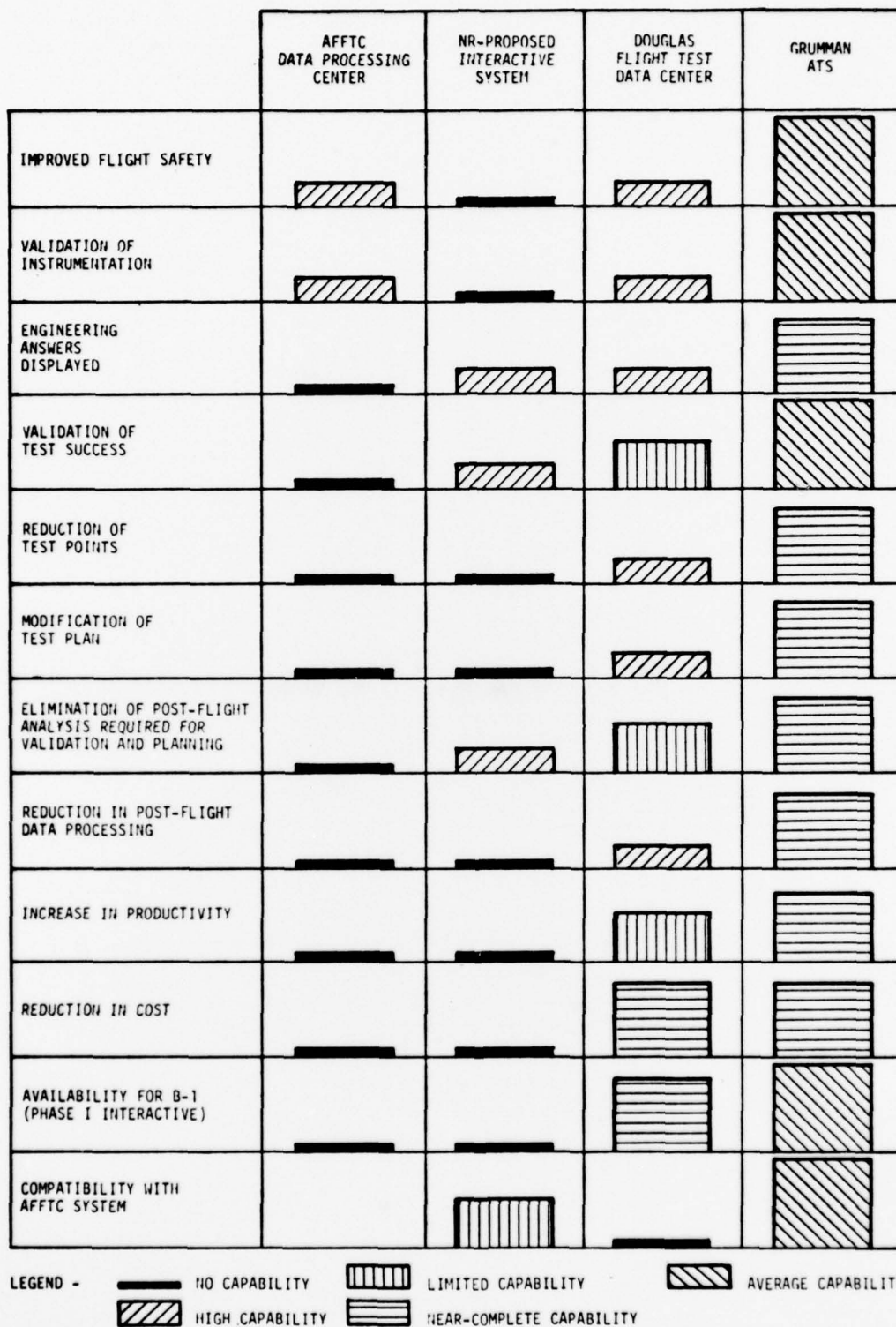


Figure 1 CONDENSED EVALUATION OF PROPOSED INTERACTIVE DATA PROCESSING SYSTEMS FOR B-1 FLIGHT TEST

Section V

MANAGEMENT ENVIRONMENT

5.1 ACHIEVING THE BENEFITS OF INTERACTIVE REAL TIME DATA PROCESSING

5.1.1 General Requirements

To achieve the benefits of Interactive Real Time Data Processing as outlined in Subsection 4.1, certain requirements must be addressed. Some of the requirements are intangible at this point because they involve advanced planning, training, and management decision. Other requirements are useful in judging and comparing systems because they describe capabilities that can already be measured.

- (1) Sound understanding and support by both Contractor (NR) and Agency (Air Force) top management.
- (2) A willingness on the part of top management to modify deliverable data requirements in order to take advantage of real-time time data analysis.
- (3) Clear definition by top management of the answers required from flight testing.
- (4) Detailed planning by the various engineering disciplines to establish the data analysis required to yield these answers.
- (5) Mathematical description by various engineering disciplines of functions to be computed in real-time analysis.
- (6) Variables to be measured and accuracy requirements for these variables.
- (7) Instrumentation to sense and transmit these variables.
- (8) Aircraft assignments and programs for getting data.
- (9) Flight planning to generate necessary data for required answers.
- (10) Training is required for Test Directors, Test Pilots, and Test Engineers from the various disciplines which will enable them to use the system effectively.
- (11) Data processing equipment to handle the large amount of real-time data.

5.1.2 Team Requirements and Previous Experience

The transition from ordinary flight test operations to the full real-time-interactive operation requires early and direct participation by the B-1 SPO and NR engineering groups in the detailed flight test planning. The most critical part of the planning is based on the need for detailed engineering predictions of expected results of each test run. This effort is essential to assure that the displays, computer analyses, and other detailed real-time programs are fully prepared. Grumman noted that in the early stages of developing the ATS their engineers were at first considerably reluctant to provide this necessary detailed information. However, once upper management provided the needed direction and authority to the engineering groups, they applied themselves, and generated the data. Only minor readjustment of personnel assignments was required at Grumman. However, it was necessary to assign a team of engineering specialists from Grumman - Bethpage to the flight test group at Grumman-Calverton to obtain the necessary close cooperation and communication between engineering and flight test personnel.

Similar negative attitudes of NR engineering personnel were detected by Calspan when investigating the engineering plans at NR/LAD*. These attitudes must be viewed with concern, but understanding, because they are generic. The simple requirement is for the engineering groups to present their design data, preliminary tests, etc. in a coherent form for ready comparison with flight test data. In this way the flight test program can be planned to permit comparison between expected and actual performance.

Calspan feels that an organizational structure similar to the one described above is necessary at NR/LAD. A dedicated group, composed of flight test personnel, applications programmers, and design engineering specialists must be formed, with the primary responsibility of preparing for real-time-interactive flight testing. These personnel must, through contact with each speciality, develop the detailed overall flight test plan (the matrix of test points, configurations, etc.) From these requirements, individual flight test plans (for a reasonable number of the early flights), integrated test blocks, predicted engineering results for these initial tests, and other basic real-time planning details can be developed. This "mini tiger" team must have the necessary support to prepare for real-time-interactive flight test operations. NR, B-1 SPO, and AFFTC personnel should be part of this team. Since Grumman is the only aircraft company with actual use experience with interactive real-time flight test planning, it would be helpful if the B-1 SPO and/or NR/LAD also contracted for Grumman personnel to assist in this planning in an advisory capacity.

Calspan would like to emphasize that developing a real-time system is well within NR/LAD's capabilities. Our only reason for suggesting an advisory role for Grumman is that because of the very short time remaining before first flight, it would be prudent to use every bit of help possible from the entire aircraft industry.

* Although the NR engineering groups have the most responsibility to generate data and hence, natural reluctance to new requirements, there may also be similar, but probably less emphatic, reluctance within the B-1 SPO. Calspan personnel did not encounter this attitude but would not really be surprised if such reluctance surfaced later.

5.2 ORGANIZATION AND PLANNING

5.2.1 Organization

The previous evaluation shows that the necessary hardware is available at AFFTC to perform Interactive-Real-Time processing of flight test data and that the Grumman ATS system could be incorporated into the AFFTC system to supply an overall system for Interactive-Real-Time data processing.

The remaining requirements for accomplishing this are not yet established. However, from the above list of requirements it is apparent that extensive planning is necessary. This planning must include the contributions of many key people in the B-1 program; not only NR personnel, but others from the B-1 SPO and the Air Force Flight Test Center. To make an Interactive-Real-Time system work, the participants must modify their approach to one of extensive preplanning, and they will require training in the application and use of the system.

If upper management decides to proceed with the interactive-real-time approach (the decision must be made at this level), they must support the effort by supplying the necessary persuasion to get the cooperation of all lower level parties. There will be considerable resistance, as with any new procedure. The detailed planning that will be necessary by the engineers representing the various disciplines is a large task and one which they will probably resist. The task of supplying the data necessary for the requirements of the various engineering disciplines will fall to the staff of the Director of Flight Test. This again will require extensive detailed planning for instrumentation, aircraft assignments, flight content scheduling, and data processing. The Director of Flight Test will have to screen the requests from engineering for duplication and over-kill, and coordinate and integrate the efforts of engineering and the flight test staff.

The NR and Air Force Flight Test Directors must integrate the efforts of all these groups, while the forcing function must be supplied by the Air Force and NR program managers to ensure the necessary participation of all. Figure 2 shows how the integration of people/activities can be planned for the B-1 program. The importance of support from top management cannot be over-emphasized. Without this support and direction, the task of the Flight Test Director would be impossible.

5.2.2 Flight Test Planning

The Air Force is faced with the problem of determining whether to proceed with the development of the B-1 or to abandon it at production decision date. The Category I flight test will be a major factor in this determination.

Therefore, goals for the flight test program must be established with production decision in mind. Along with establishing the goals must come methods of verifying that they have been reached and test programs to implement these methods.

The goals will probably be established on the basis of performance against criteria in propulsion, structures, and stability and control, which when taken together will yield the desired overall performance.

Data analysis techniques for measuring the B-1 system against these goals and criteria must be defined.

And finally, detailed flight test plans must be formulated that will yield as much useful data as possible and expand the envelope of testing as rapidly as flight safety will permit.

This entire process will be an iterative procedure to arrive at a realistic flight test program. It will require a coordinated effort of specialists in flight test, propulsion, structures, stability and control, performance, instrumentation, and data processing.

Section VI

CONCLUSIONS

The following is a list of Calspan's essential conclusions, which are supported in this report by the "facts" that were gathered (the "facts" gathered in this study are sometimes subjective expert engineering judgment and must be considered as factual evidence of the current status of the flight test industry), and by Calspan's commentary and secondary conclusions as identified in the text.

Calspan's conclusions are relative to the following question: What are the capabilities/advantages, options, shortcomings, and cost-effectiveness of the candidate facilities and/or systems for selecting either a real-time or non-real-time B-1 Flight Test Program?

These conclusions are as follows:

- (1) The AFFTC computing center has the potential to provide real-time-interactive data processing on the telemetry data from the B-1 aircraft.
- (2) The digital and analog data transmitted from the B-1 aircraft (not including some kinds of avionics data), format or type, should pose no problems in being accepted by the receiving station and preprocessing equipment. Programming will be necessary.
- (3) The McDonnell-Douglas and NE real-time systems, as presently envisioned, do not satisfy enough of the operational and data handling requirements to be significant improvements over the present general plans for the B-1 flight tests (Phase I and beyond).
- (4) The Grumman real-time-interactive Automatic Telemetry System (ATS), an operational and proven system and is the only practical candidate for a real-time system on the B-1 flight test program.
- (5) The commitment to use a real-time-interactive flight data processing system only begins with the commitment to obtain the necessary hardware and software. It is even more important to have management and top engineering level commitment to proper flight test plan preparation for the use of the real time system. Efficient utilization is only possible if there is such a commitment.

- (6) The savings in lost flights, data repeats, flight hours per data point, total flights per major test objective, etc. can amount to overall test program savings of as much as 50%. When a test period is fixed this implies that test accomplishment will be about twice that of a non-real-time operation.
- (7) A real-time-interactive system would be a useful, practical, economically sound investment for the Air Force. The B-1 would benefit from its use in being able to obtain more useful data prior to the production decision date and during the follow-on test phases (categories).
- (8) Time is of the essence in incorporating a real-time system in the AFFTC. If a go-ahead decision cannot be made within the next month, the only data handling capability will be the NR/LAD system for post flight analysis and the extremely limited on-site strip chart monitoring.
- (9) The AFFTC computer facility needs help. The real-time induced restructuring will serve a dual purpose in making the overall system more reliable and efficient as well as providing the real-time-interactive capability.
- (10) The McDonnell-Douglas and the Grumman installation costs were recovered on the first program using them. There is every reason to believe that even more favorable savings are possible for the B-1 program since the hardware installation is already available and the major programming effort is complete.
- (11) The real-time approach will not be of any value if NR does not commit itself to using and preparing to use it to the fullest extent possible.

Section VII
RECOMMENDATIONS

- (1) The AFFTC and B-1 SPO should initiate a contract with Grumman as soon as possible to incorporate a real-time-interactive data handling system at the AFFTC.
- (2) NR/LAD, B-1 SPO, AFFTC and Grumman should form and operational (mini-tiger) team with sufficient authority to obtain personnel (B-1, AFFTC and NR) and priorities to generate the necessary flight test procedures, plans, requirements etc., to permit efficient use of an AFFTC real-time-interactive system by the B-1 Roll-out date. The Grumman role should be advisory to the Air Force in such a fashion that Grumman and NR/LAD responsibilities are nonoverlapping.
- (3) The AFFTC and Grumman should be responsible for the hardware installation, software, and set-up of the real-time system at the AFFTC.
- (4) Grumman and NR/LAD should review the B-1 flight test objectives, data analysis requirements and instrumentation with the goal to use or adapt as much of the existing Grumman analysis and display programs to B-1 needs.
- (5) The B-1 SPO should obtain NR/LAD full commitment to the use of the real-time-interactive system. This of course does not rule out the continued use of the NR/LAD post-flight analysis procedures as presently planned. It only reduces the need for rapid batch results turnaround.
- (6) The real-time-interactive system should not be considered further if either (1) Grumman has not been given a go-ahead by February, or (2) commitment of AFFTC and NR/LAD personnel to define the flight test program is not made.

Previously it was pointed out that the goals of flight test data processing are about the same regardless of whether interactive-real-time or post flight analysis is used. Therefore integrated planning for flight test data analysis should be underway.

Because of this it is also recommended that

- (7) NR and B-1 SPO establish the specific goals for flight test.
- (8) NR and Air Force engineering determine the necessary data analysis and report content required to establish that these goals are satisfied.

- (9) NR engineering define the numerical computation and data display required to accomplish the analysis and report.
- (10) NR and AFFTC data processing be directed to prepare necessary software.
- (11) NR and B-1 SPO establish a schedule for the accomplishment of the above. This schedule should include bench marks for the completion of the specific tasks that are established by (7) - (10) above.